

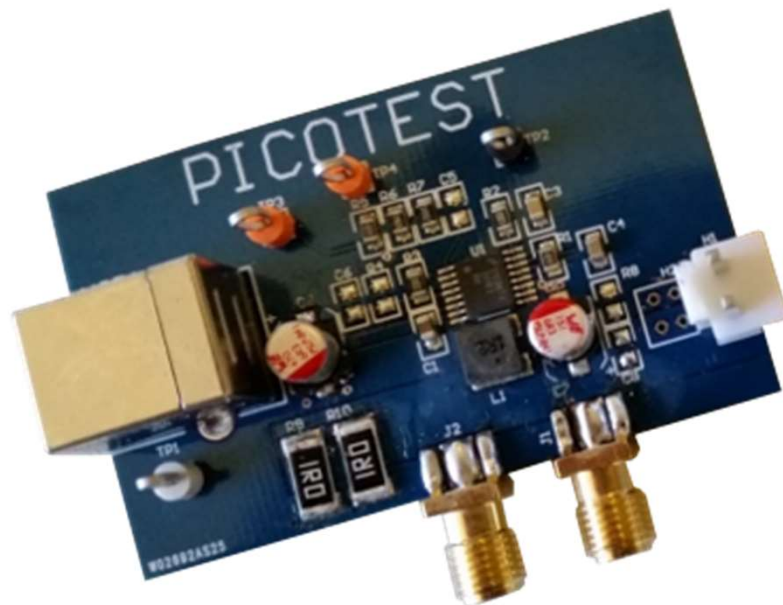
Measure, Model and Simulate Capacitors

Heidi Barnes

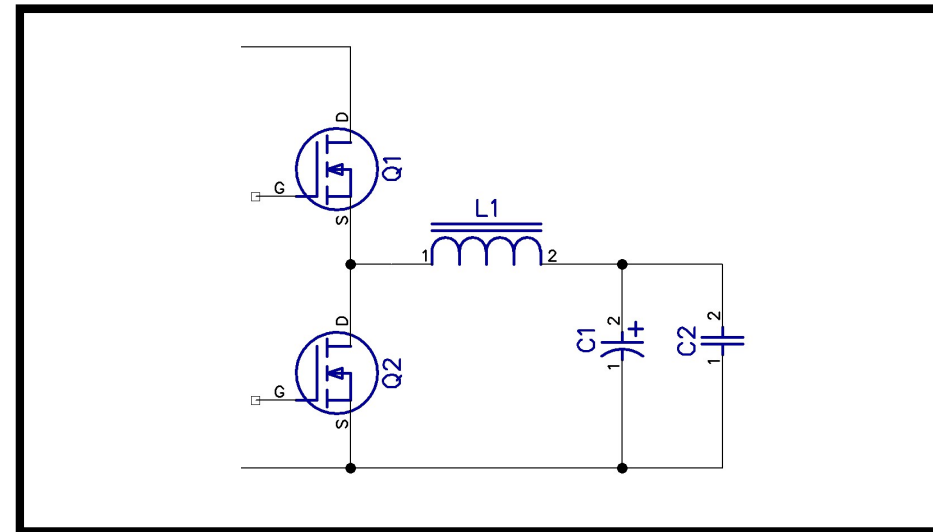
2020.3.12

Keysight Power Integrity Applications Expert

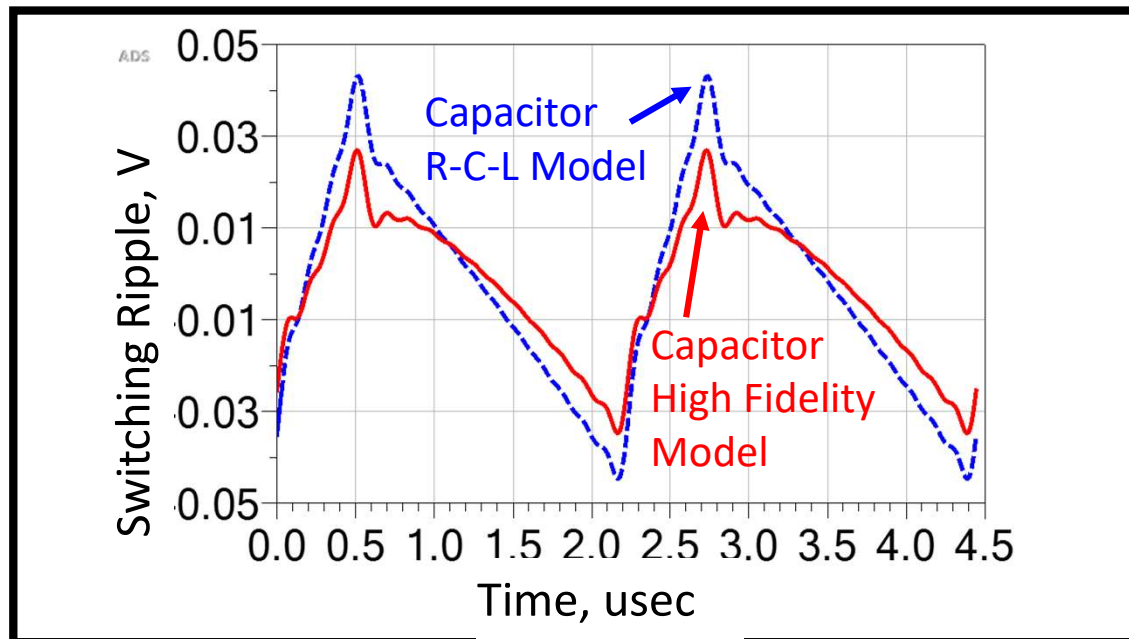




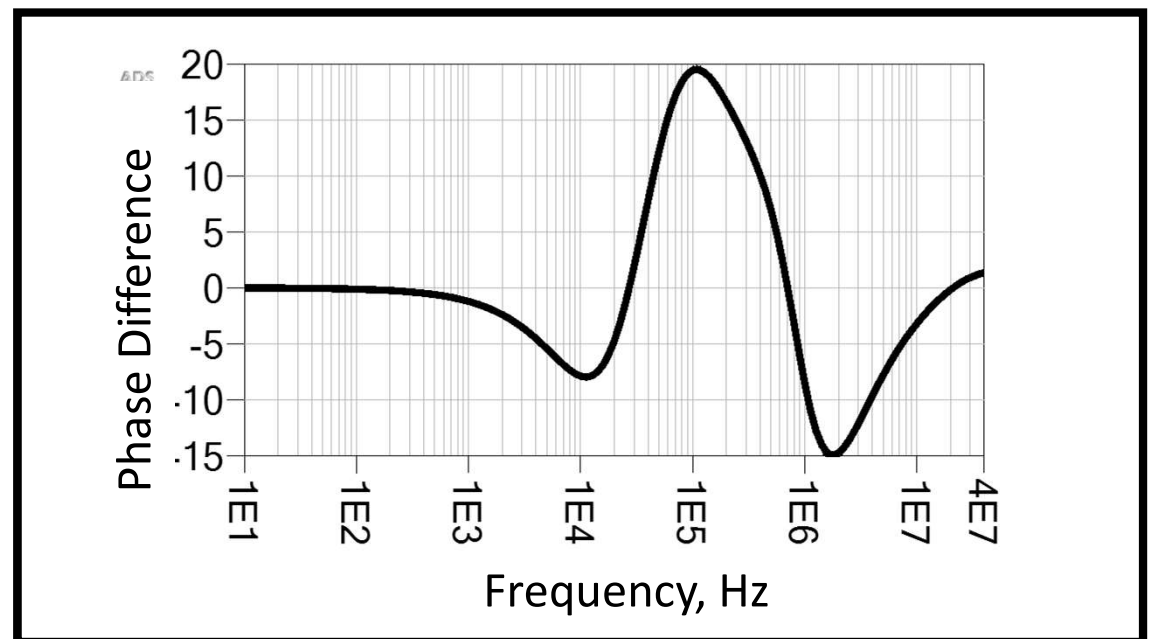
Voltage
Regulator
Module

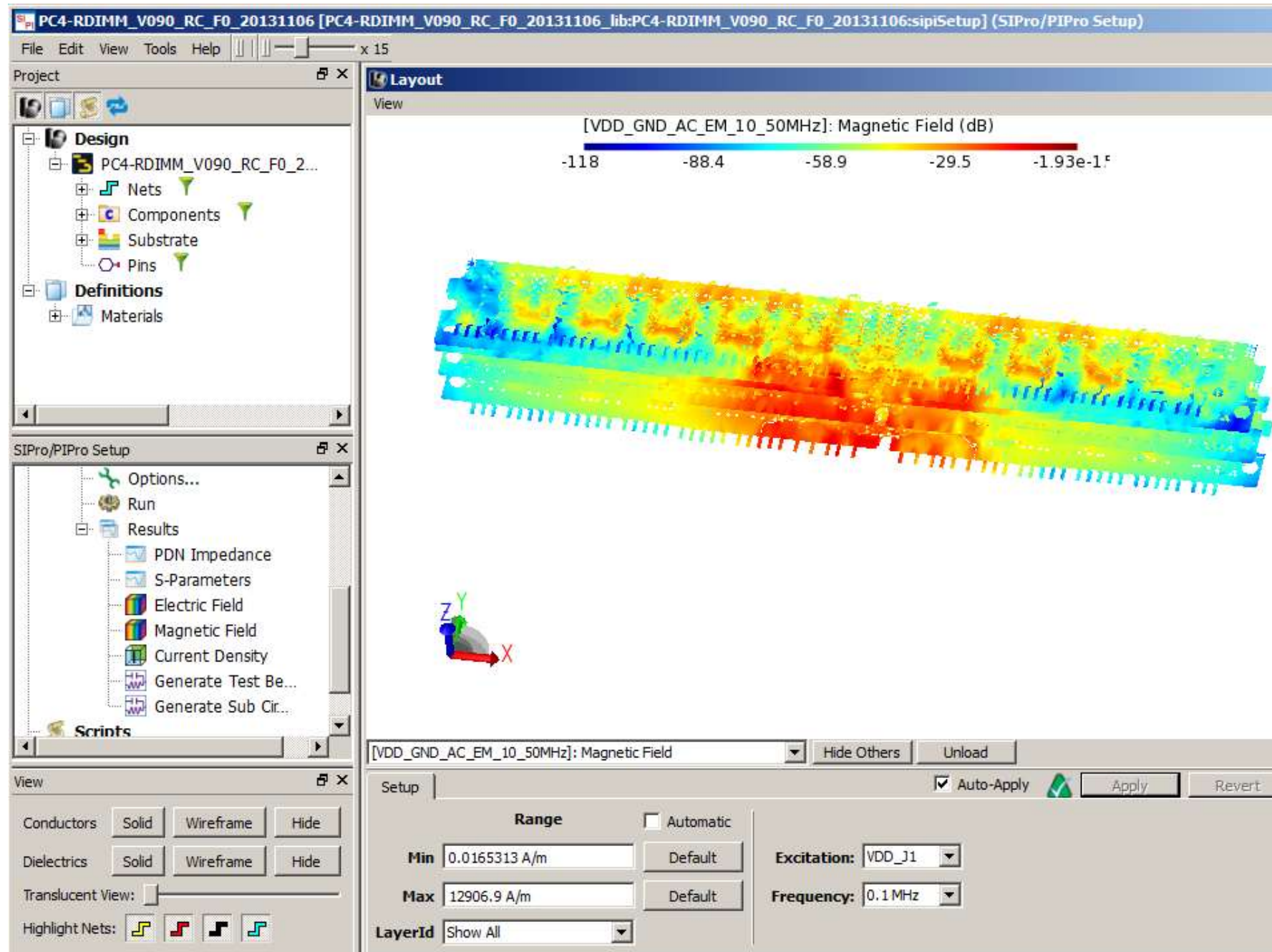


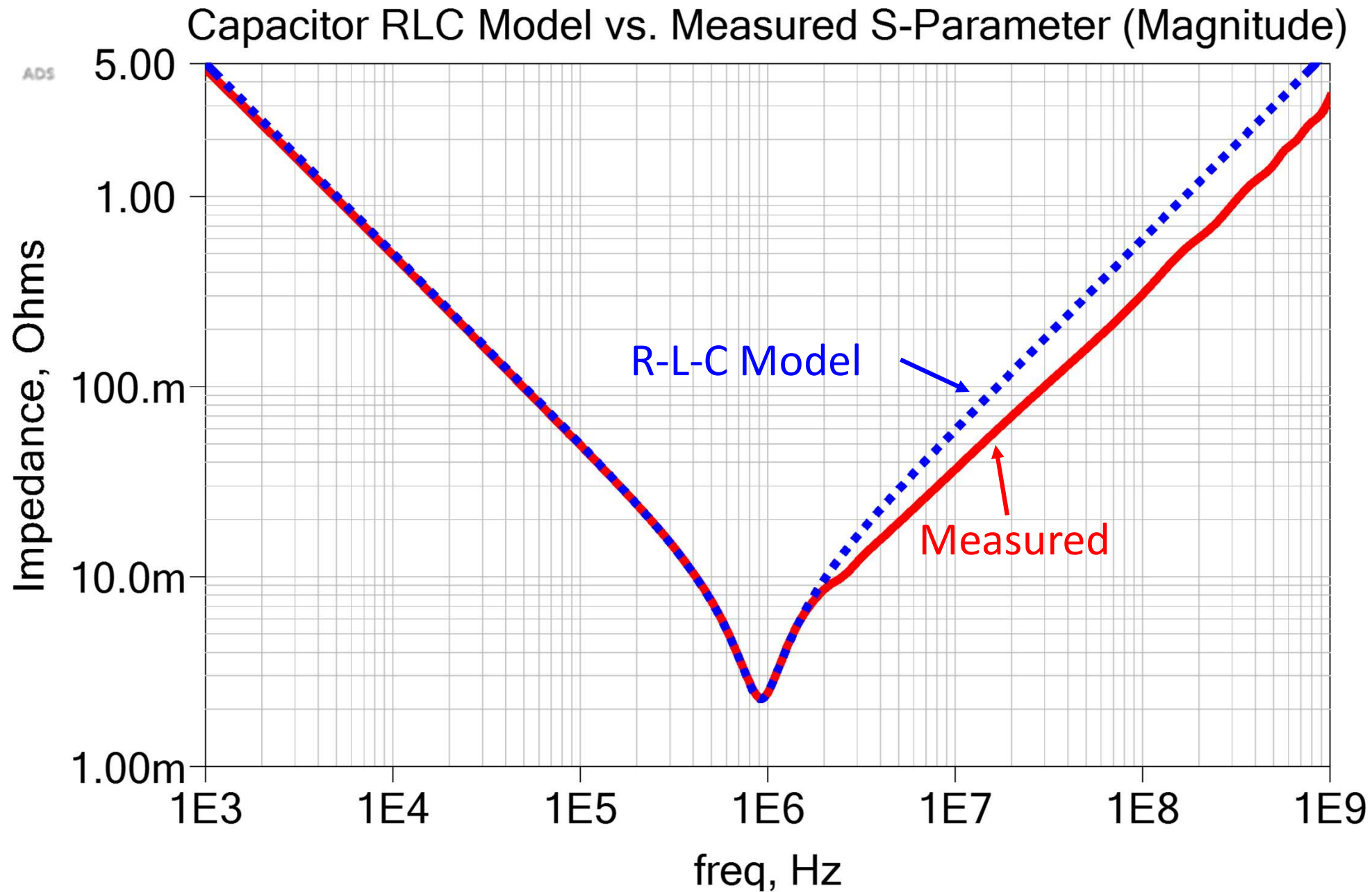
Switching Ripple
Capacitor RLC vs High Fidelity Model



Phase Difference
Phase(RLC Model) – Phase(High Fidelity Model)



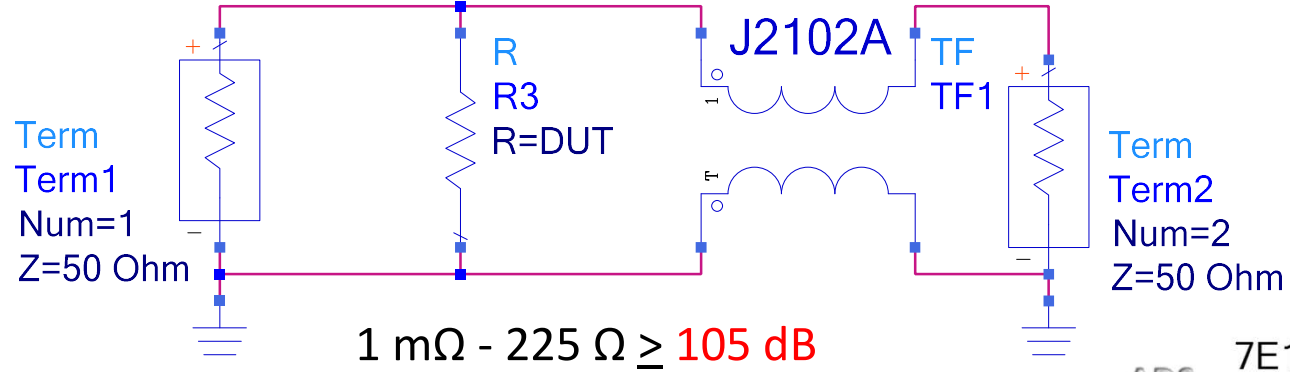




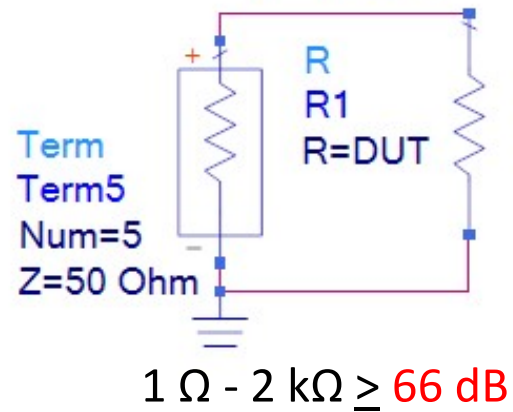
Key Topics

- How to perform a modified 2-port shunt through measurement technique for high fidelity data
- Why different simulation models are needed for SPICE and EM simulators
- How an optimizer can help create the high fidelity models from the measurements

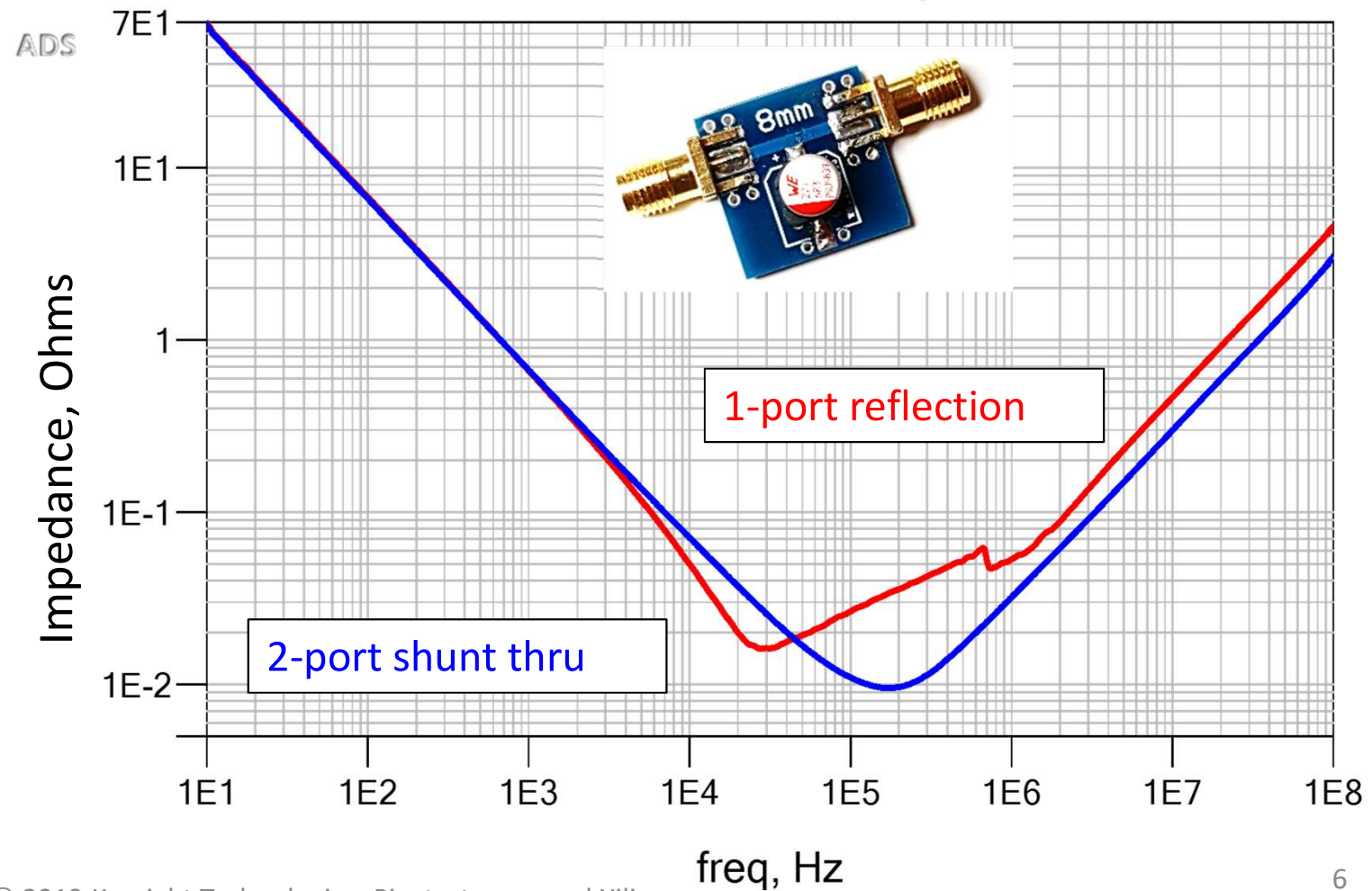
2-Port Shunt



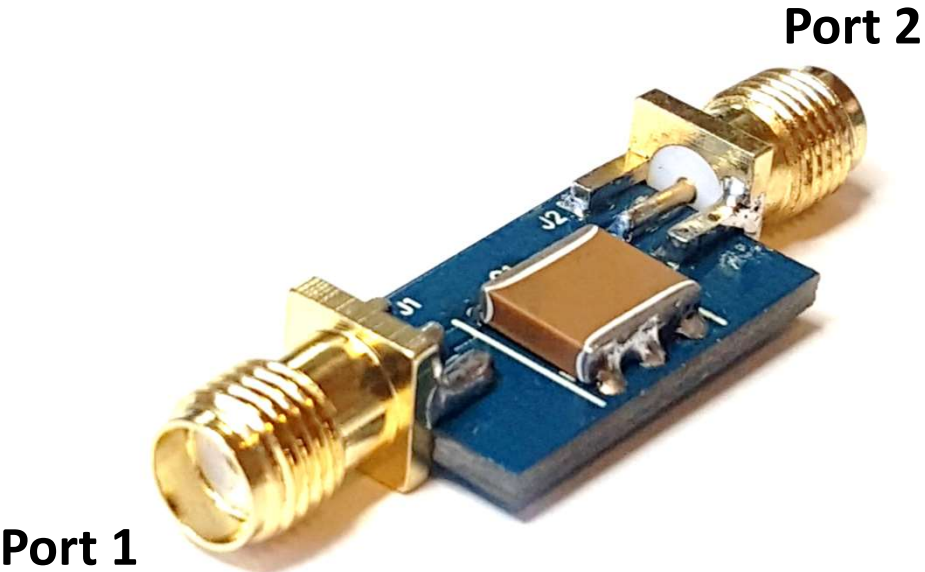
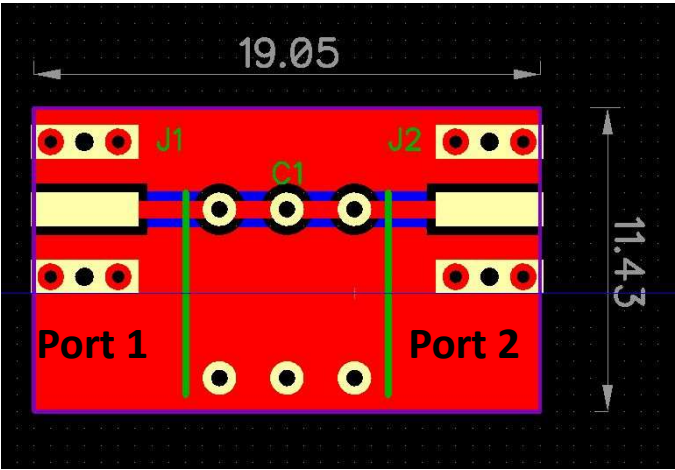
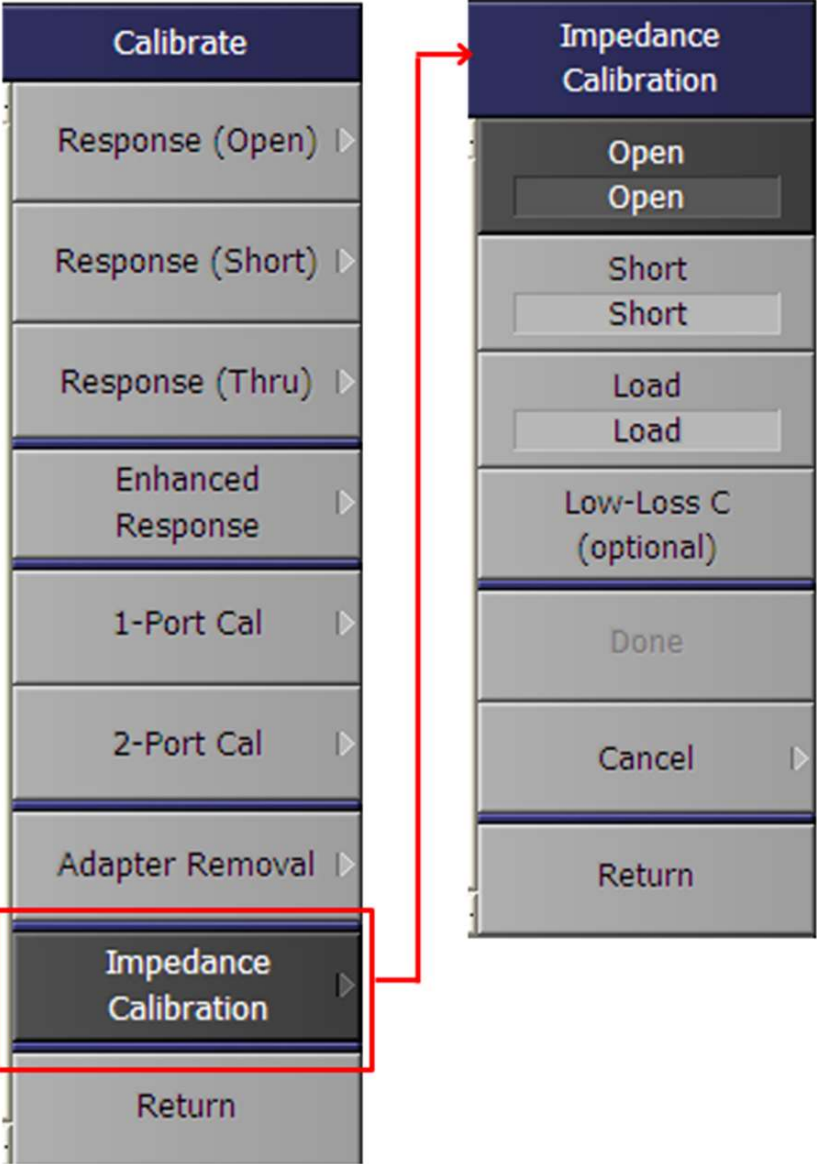
1-Port

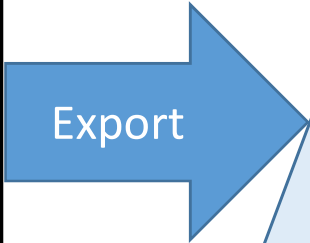
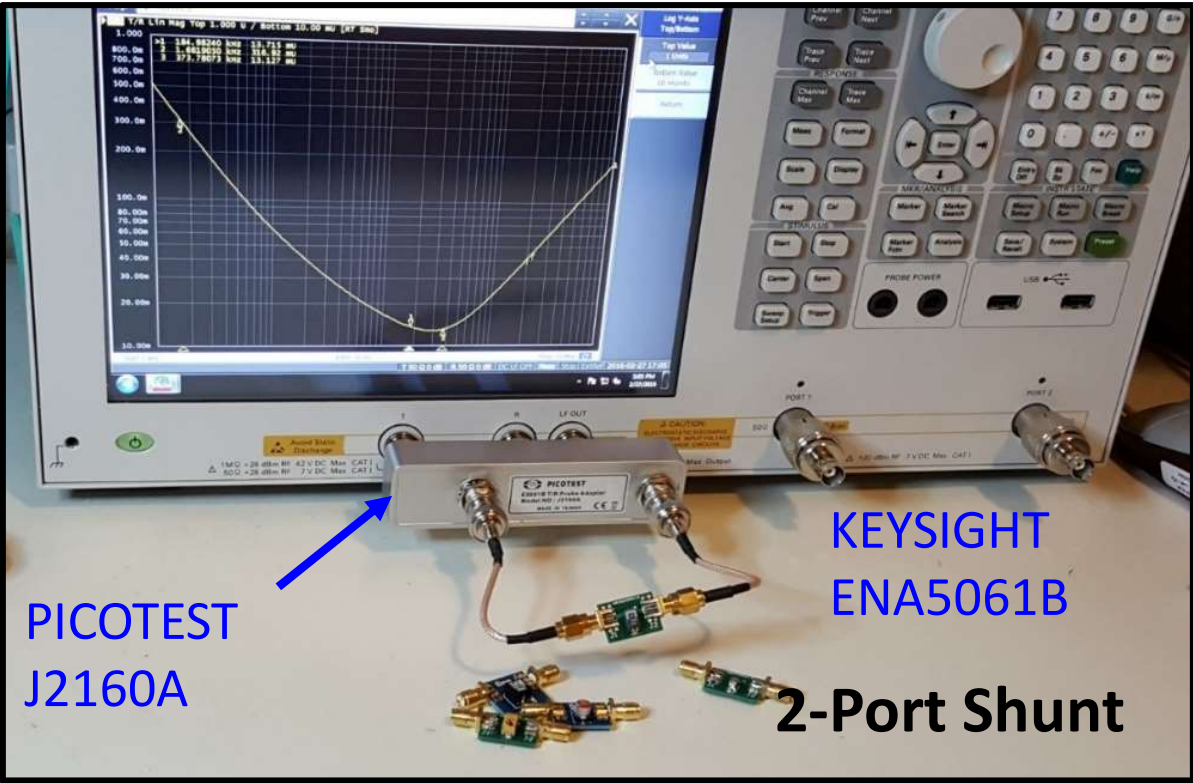


220uF Aluminum Polymer



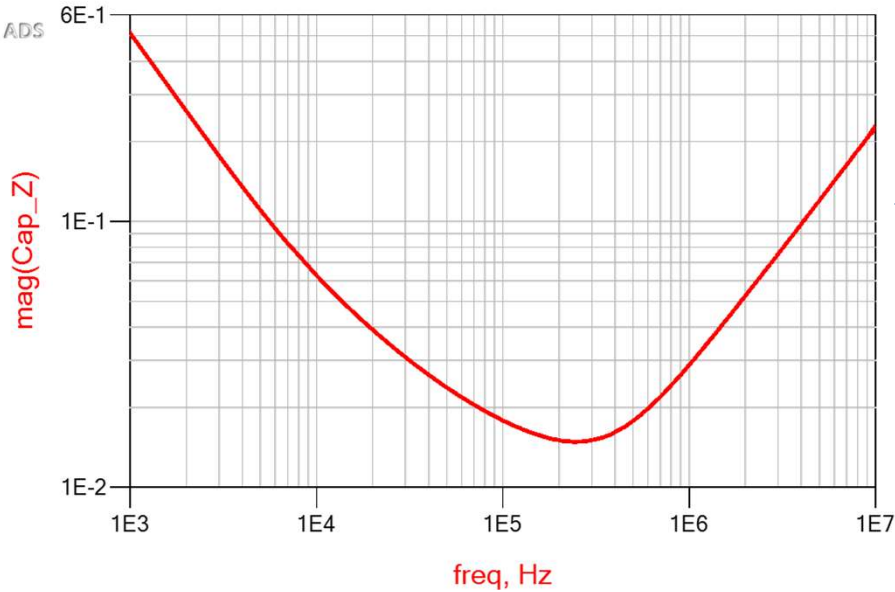
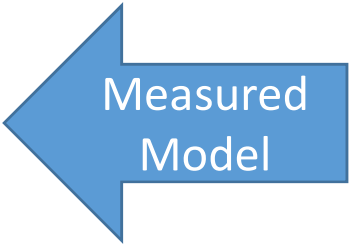
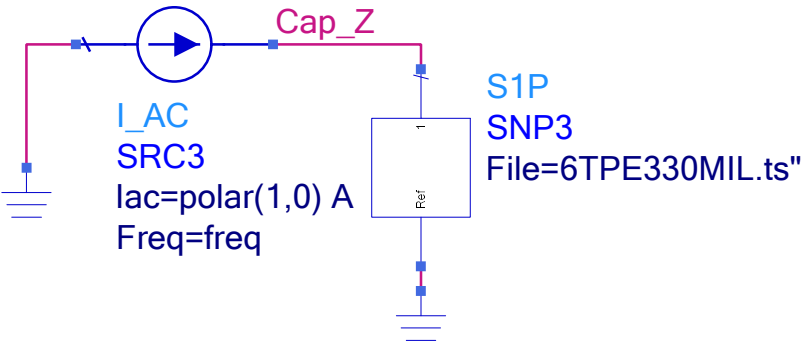
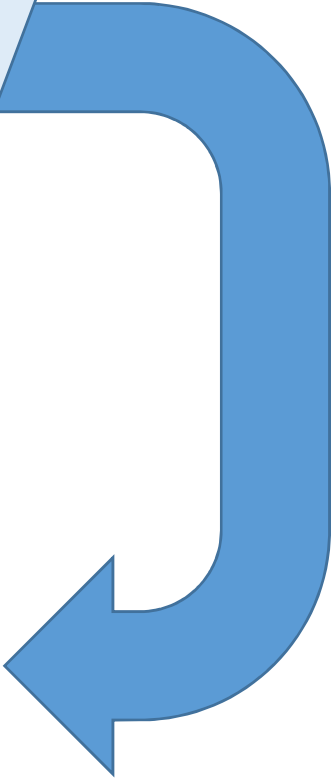
2-Port Shunt Set-up



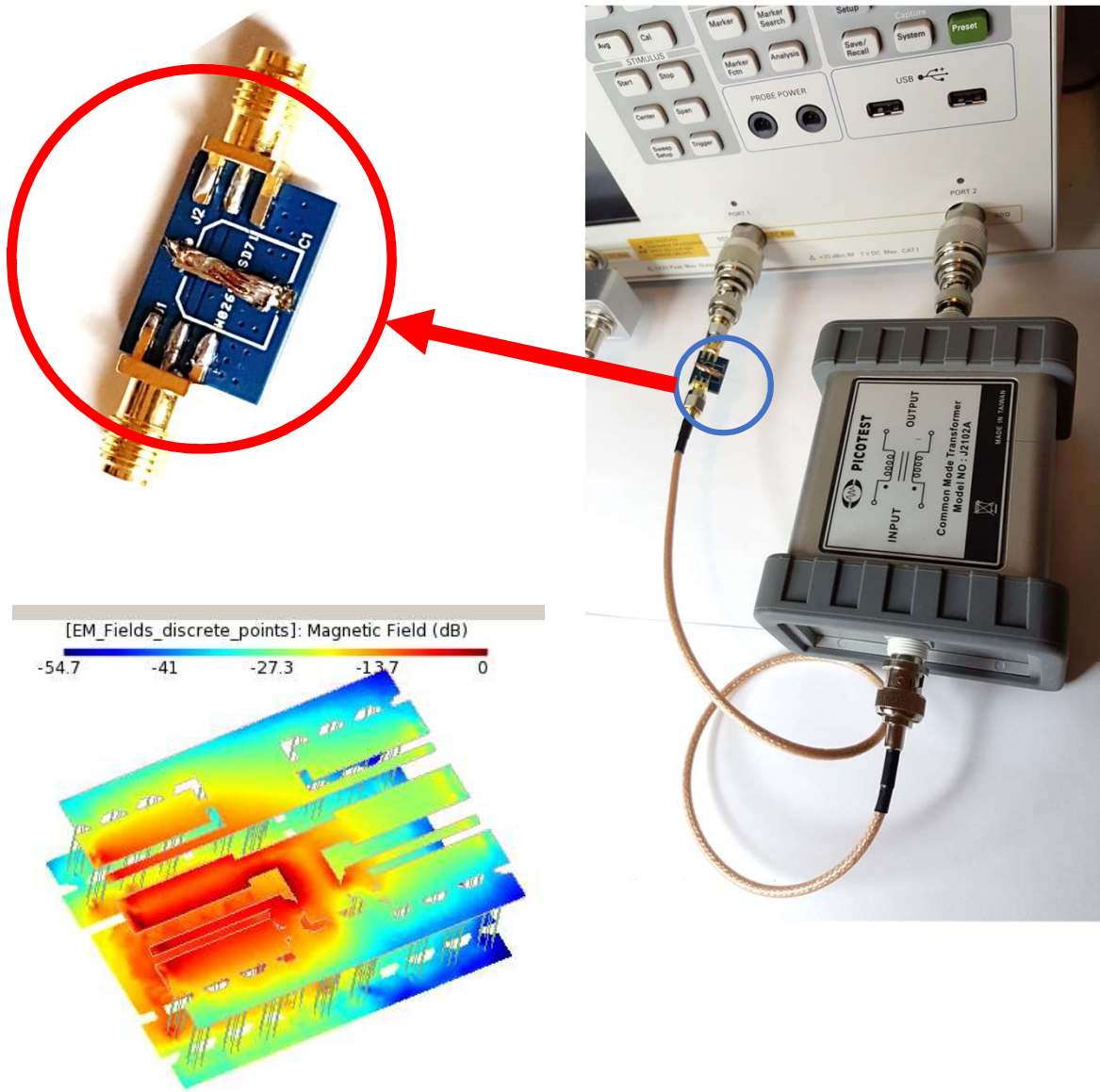


Touchstone S-Parameter file

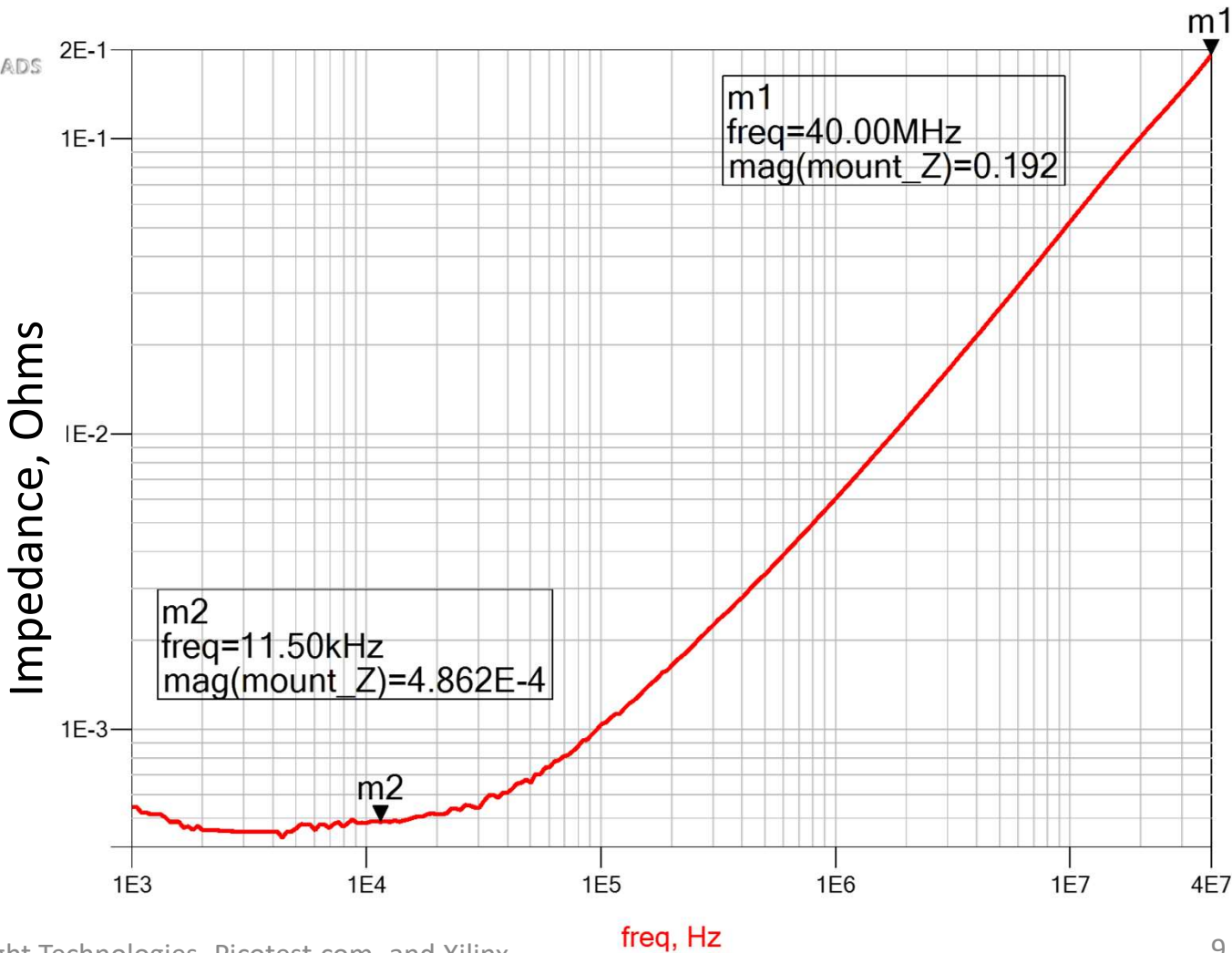
```
# Hz Z RI R 50
[Number of Ports] 1
[Number Of Frequencies] 201
[Network Data]
!freq      ReZ11      ImZ11
1000.00    0.121123   -1.537176
1047.128548 0.111947   -1.468758
1096.478196 0.104285   -1.403602
1148.153621 0.097308   -1.341032
1202.264435 0.090883   -1.280776
1258.925412 0.085359   -1.224046
1318.256739 0.079624   -1.169881
1380.384265 0.075118   -1.117441
1445.439771 0.070178   -1.067565
1513.561248 0.066014   -1.020212
1584.893192 0.061078   -0.974788
1659.586907 0.058686   -0.930364
```

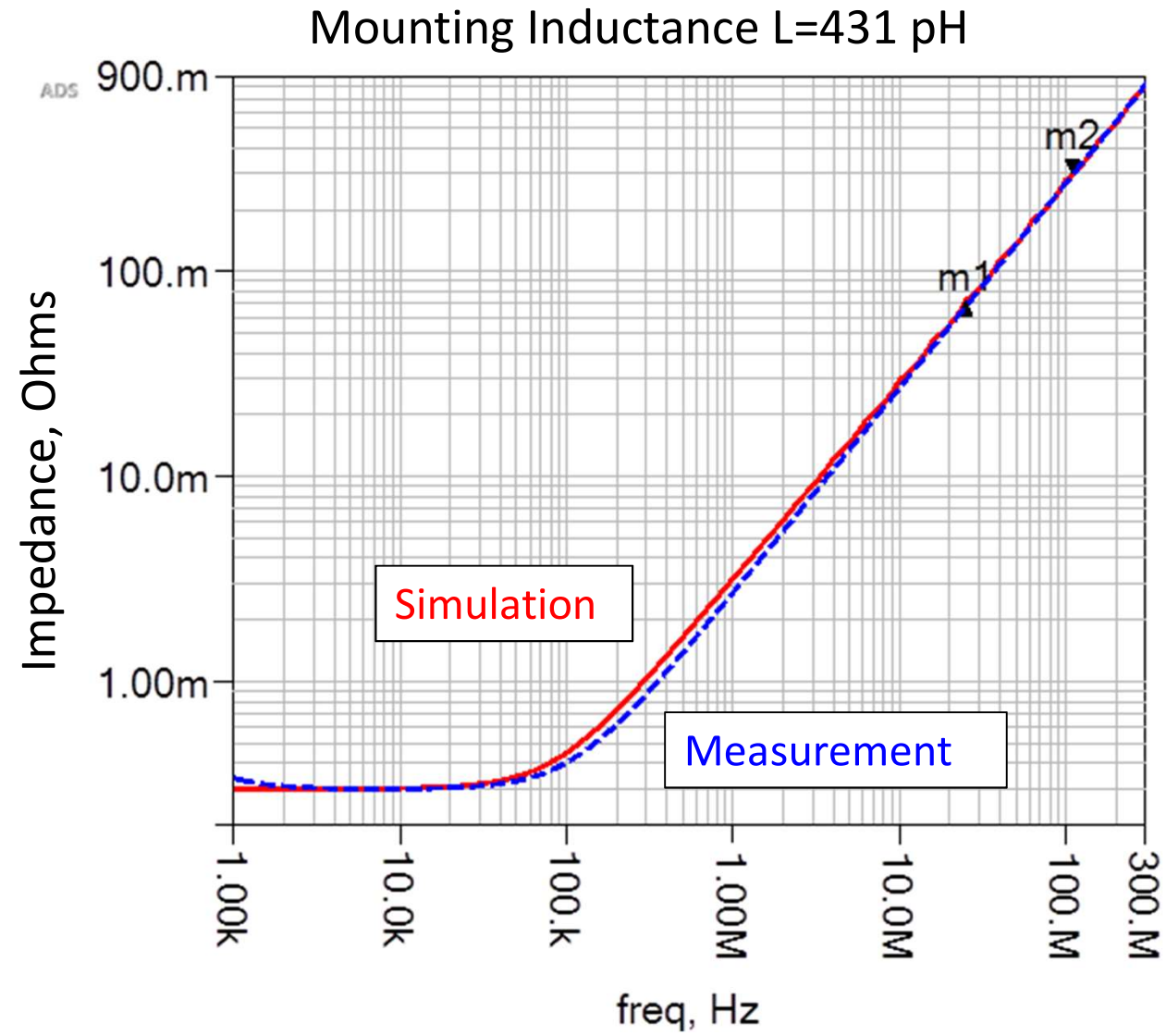
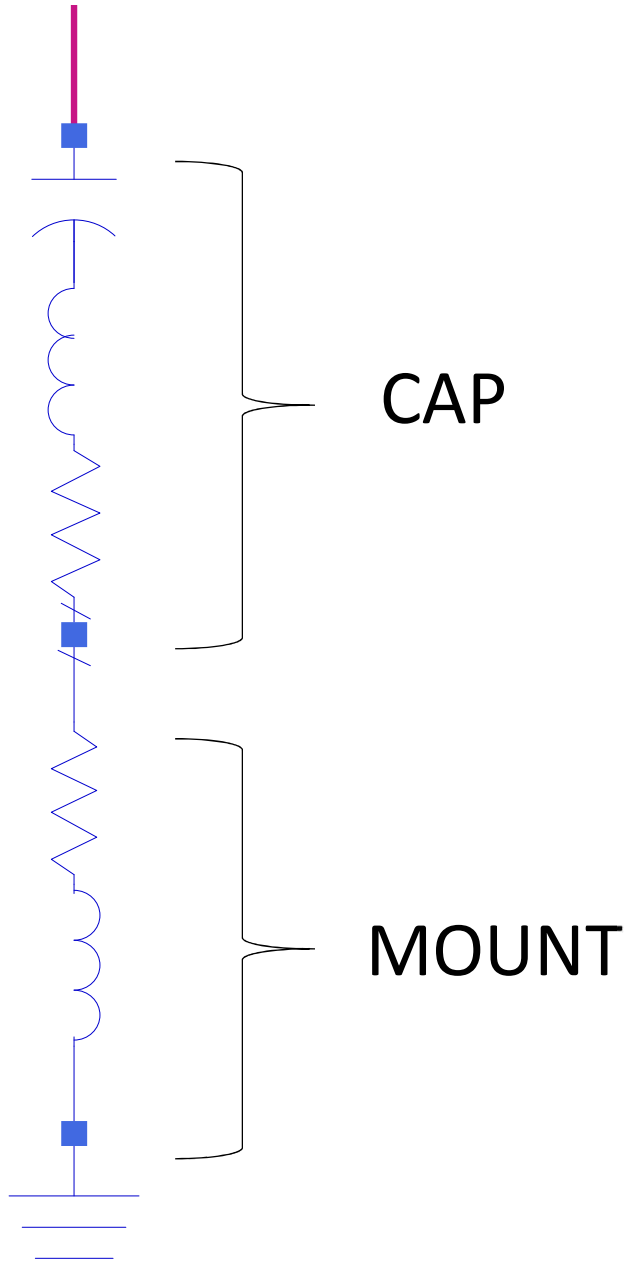


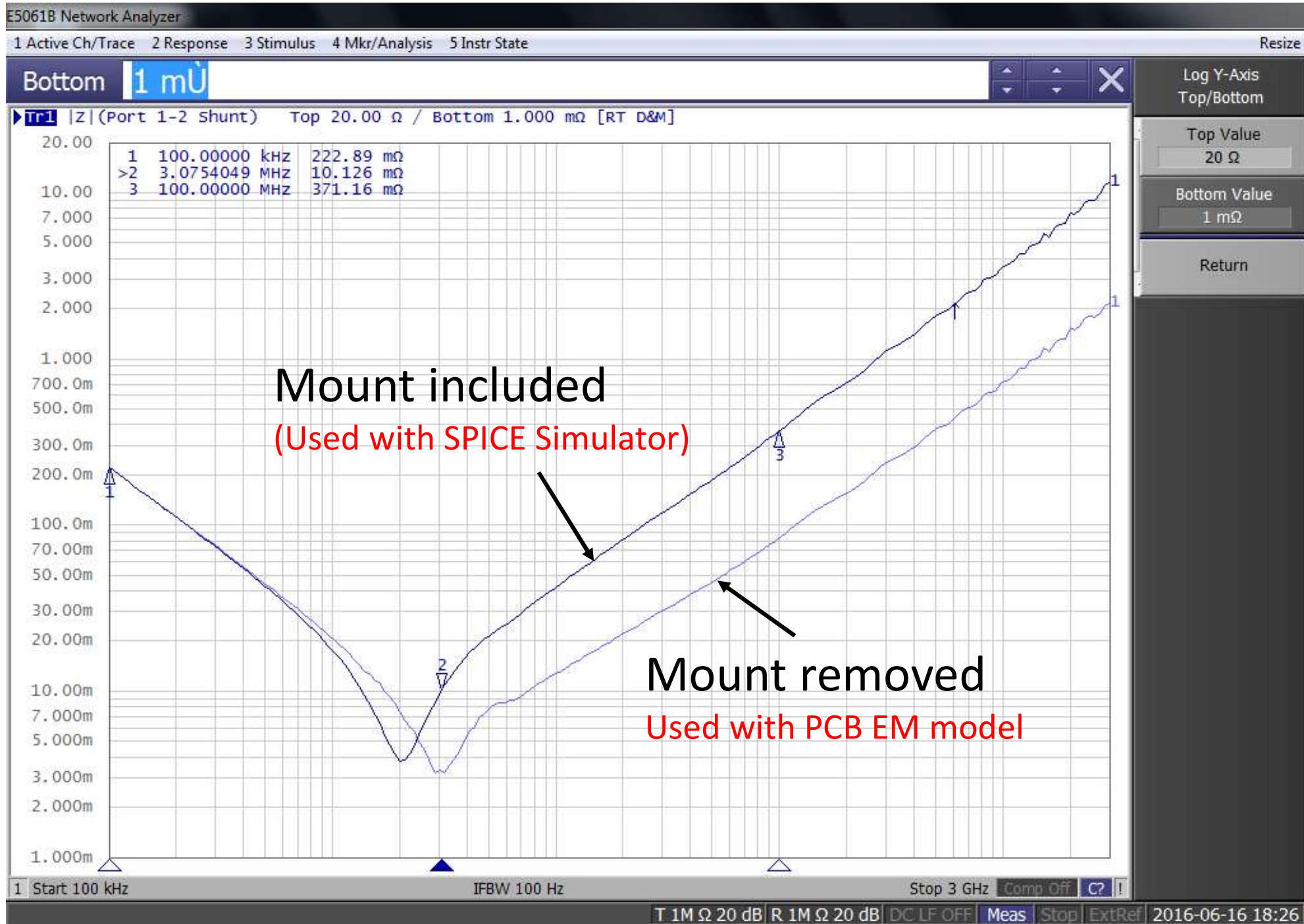
Mounting Inductance Measured with Short to Ground

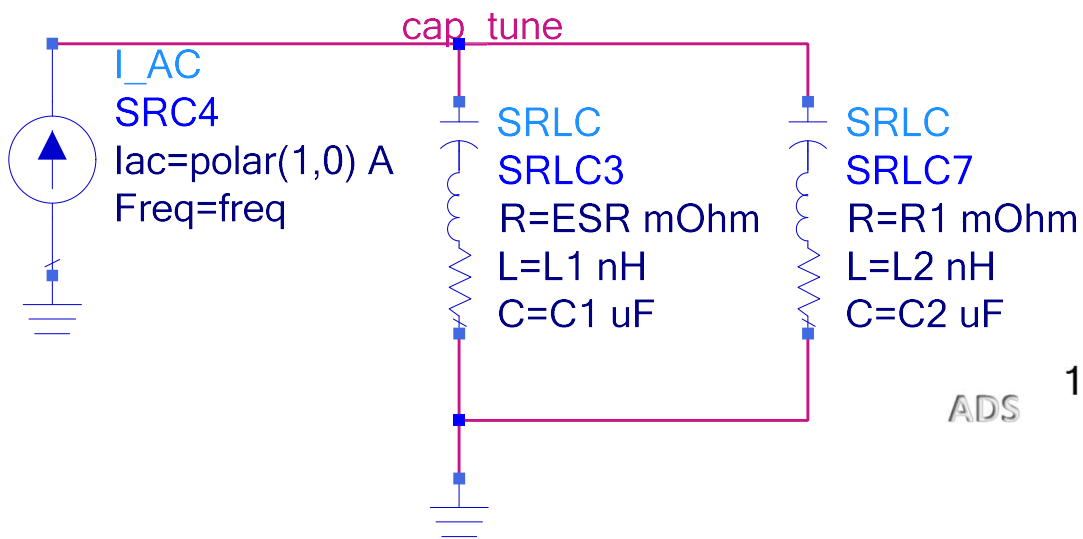


$$L_{mount} = \frac{0.192}{2\pi \cdot 40MHz} = 764pH$$





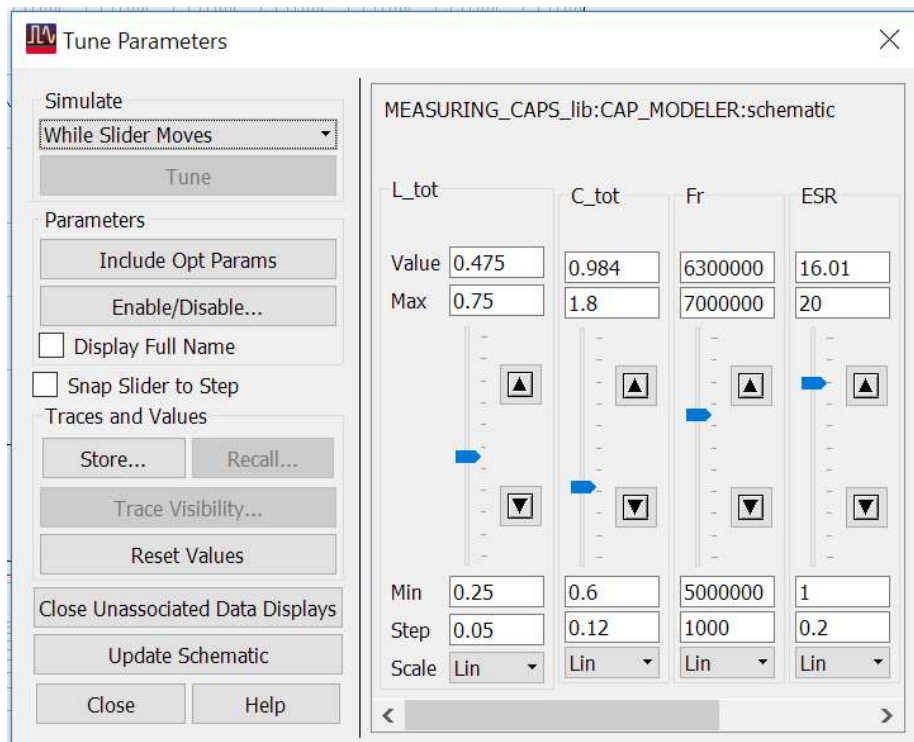
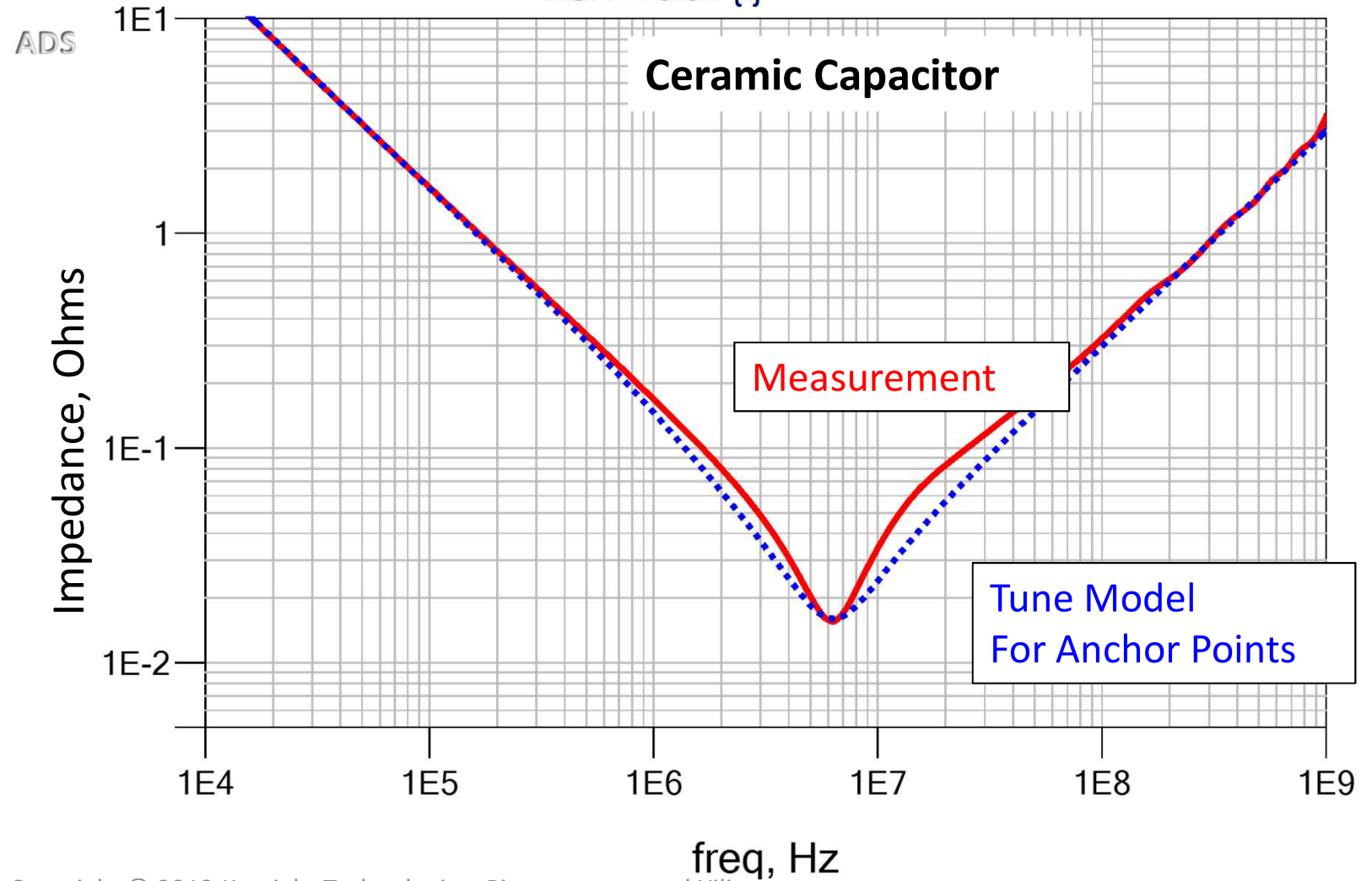




Anchor values

Var
Eqn

VAR
VAR1
L_tot=0.475 {t}
C_tot=0.984 {t}
Fr=6300000 {t}
ESR=16.01 {t}



Tune Parameters

Simulate
While Slider Moves

Tune

Parameters

Include Opt Params

Enable/Disable...

☐ Display Full Name

☐ Snap Slider to Step

Traces and Values

Store... Recall...

Trace Visibility...

Reset Values

Close Unassociated Data Displays

Update Schematic

Close Help

C1

0.814

1.5

0.1

0.1

Lin

R1

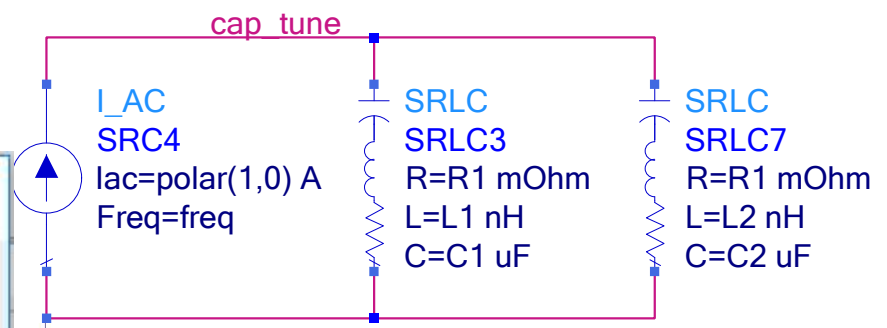
435.4

466.5

0.1

31.1

Lin



Shaping values

Var

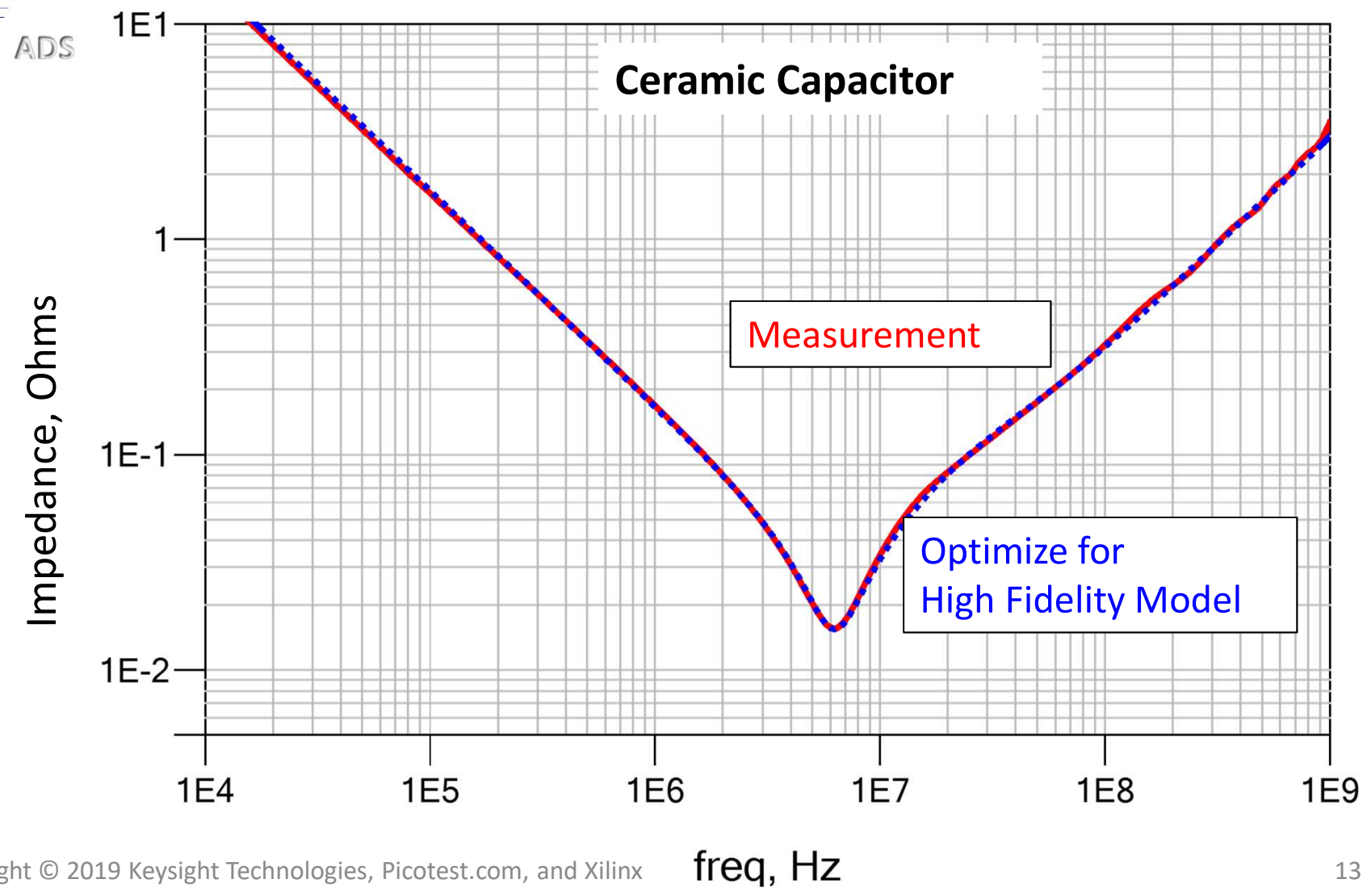
Eqn

VAR

VAR3

C1=0.75 {t}

R1=311 {t}



Anchor values

Var
Eqn

VAR
VAR9

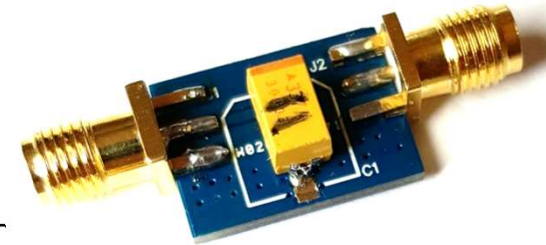
$L_{tot}=1.76 \{t\}$
 $C_{tot}=330 \{t\}$
 $F_{break}=11520 \{t\}$
 $R_{break}=42 \{t\}$
 $F_{res}=600000 \{t\}$
 $R_{res}=12 \{t\}$

Default values and tuning

Var
Eqn

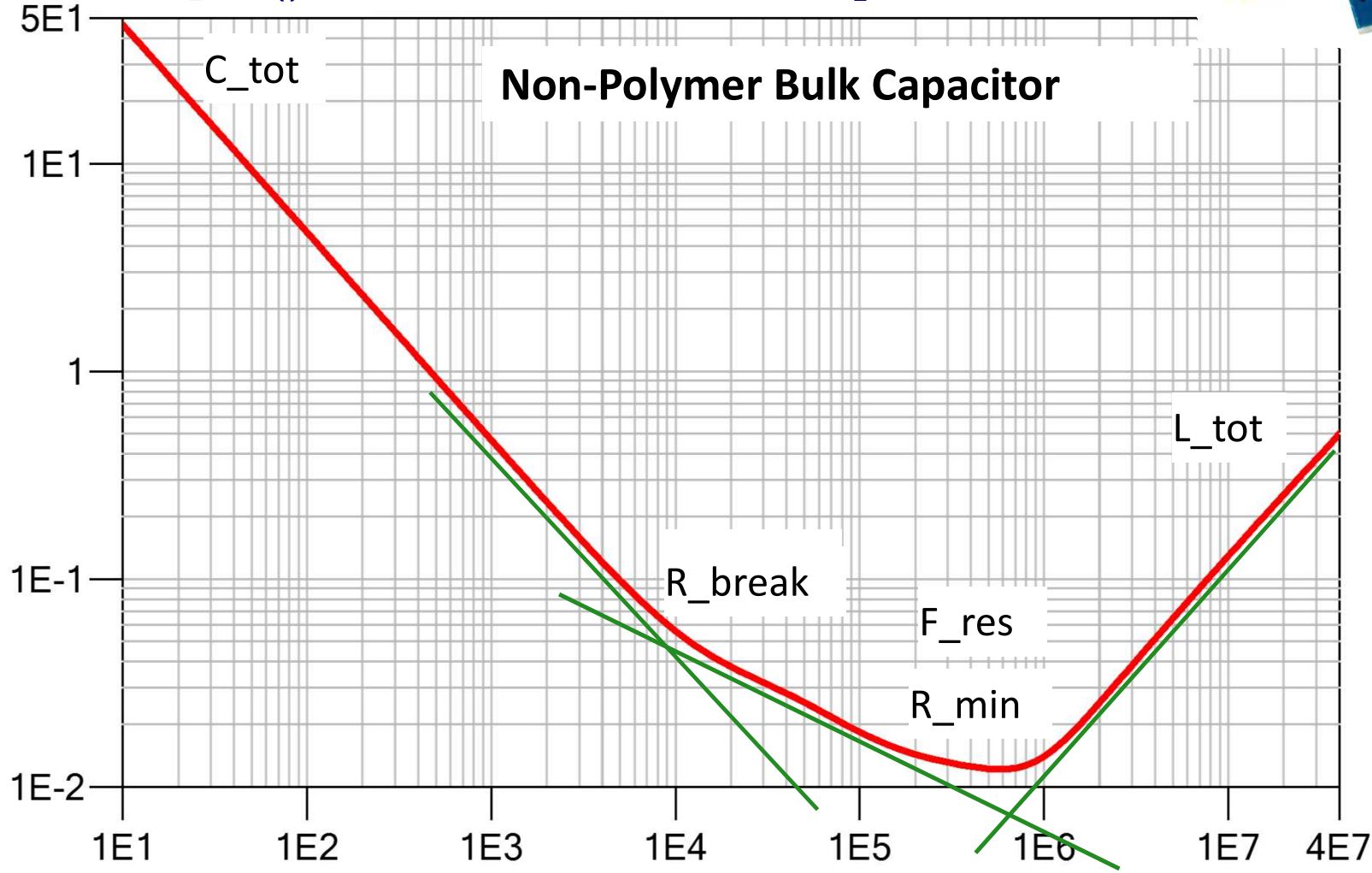
VAR
VAR6

$C1=K1*1E9/(8.89*F_{break}*R_{break})$
 $R2=K2*R_{res}$
 $L2=K3*5E15/(39.5*F_{res}*F_{res}*C_{tot})$
 $C3=K4*1E9/(15*F_{res}*R2)$
 $R4=K5*R_{res}$
 $R3=K6*R_{res}$



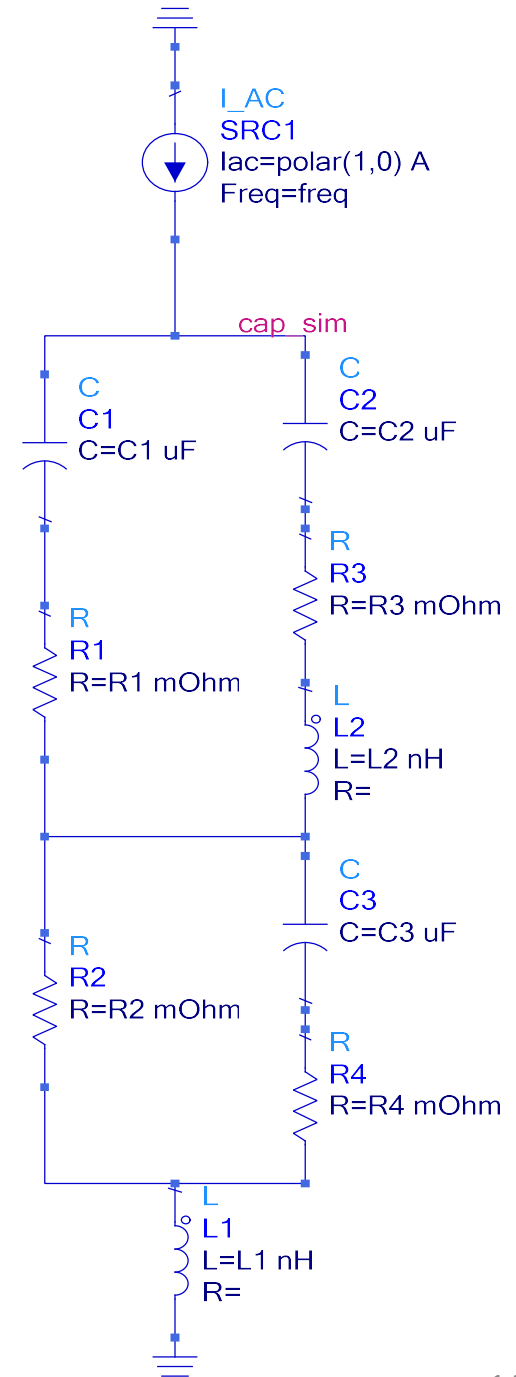
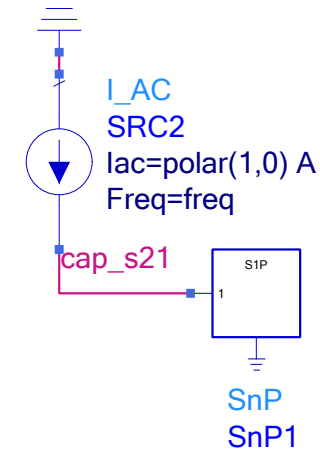
ADS

Measured Impedance, Ohms



freq, Hz

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Before Optimization

Shaping values

Var
Eqn

VAR

VAR12

K1=1 {t} {o}
K2=1 {t} {o}
K3=1 {t} {o}
K4=1 {t} {o}
K5=1 {t} {o}
K6=1 {t} {o}

Meas
Eqn

MeasEqn

cap_err

cap_err=mag(cap_meas)-mag(cap_sim)
cap_meas=cap_s21*25/(1-cap_s21)

GOAL

Goal
OptimGoal1
Expr="cap_err"
SimInstanceName="AC1"
Weight=1
LimitName[1]="limit1"
LimitType[1]="EqualTo"
LimitMin[1]=0
LimitMax[1]=0

OPTIM

Optim
Optim1
OptimType=Random
MaxIters=1000
UseAllOptVars=yes
UseAllGoals=yes
GoalName[1]=
SaveAllTrials=no

After Optimization

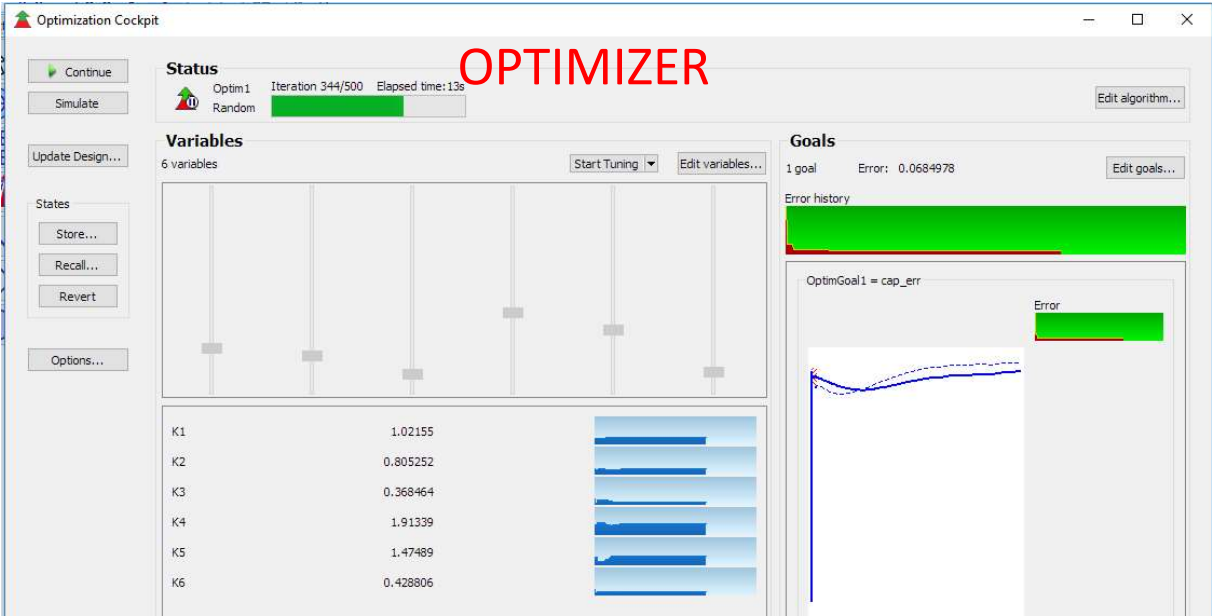
Shaping values

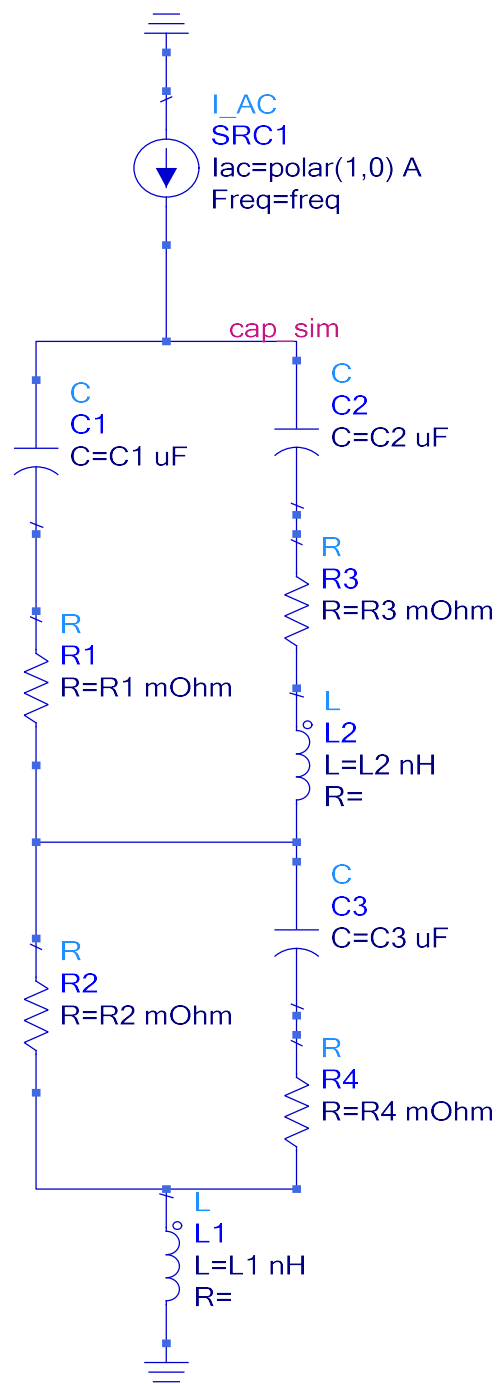
Var
Eqn

VAR

VAR11

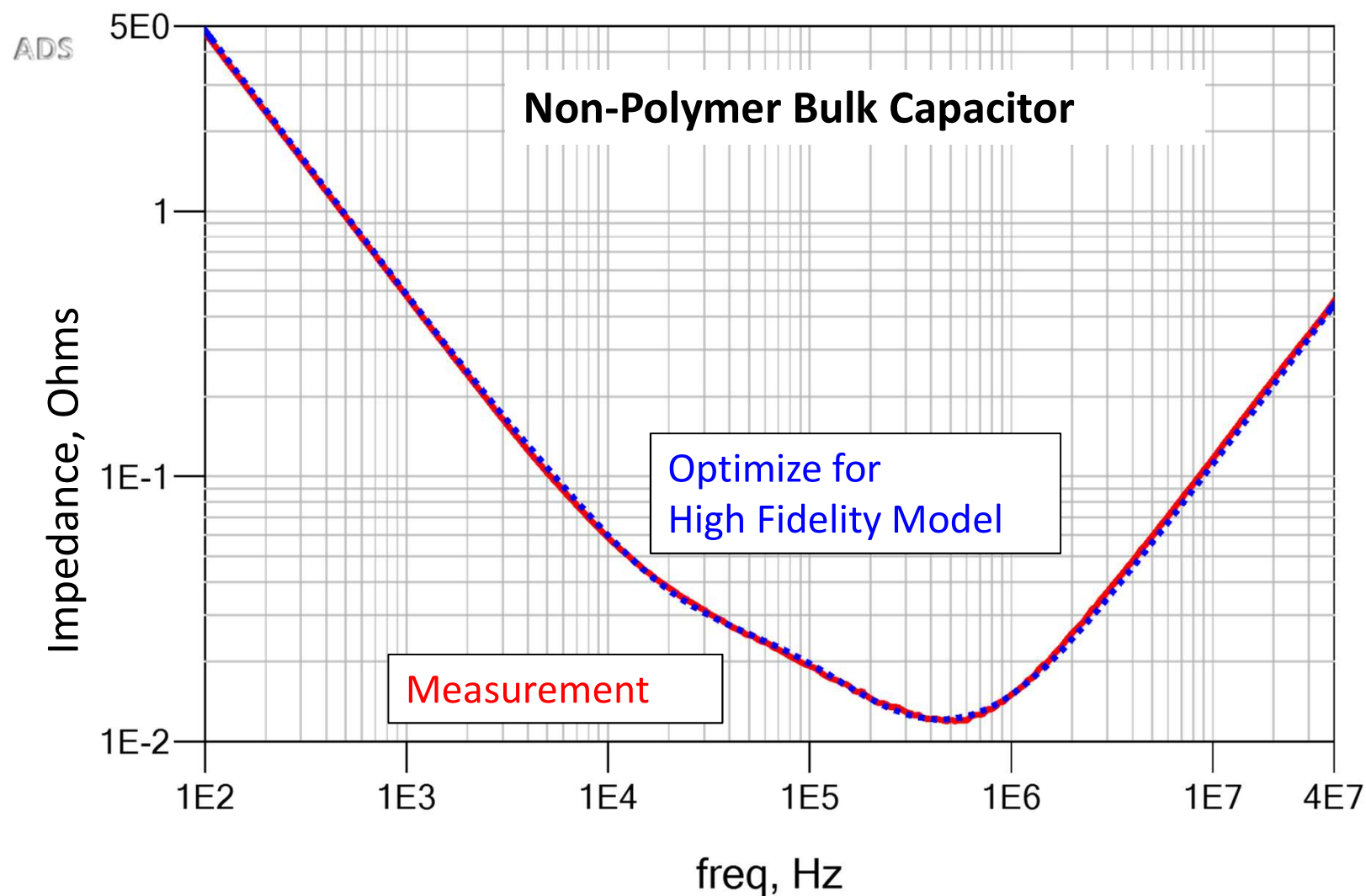
K1=1.00876 {t} {o}
K2=0.837194 {t} {o}
K3=0.41982 {t} {o}
K4=2.09546 {t} {o}
K5=1.56776 {t} {o}
K6=0.409425 {t} {o}





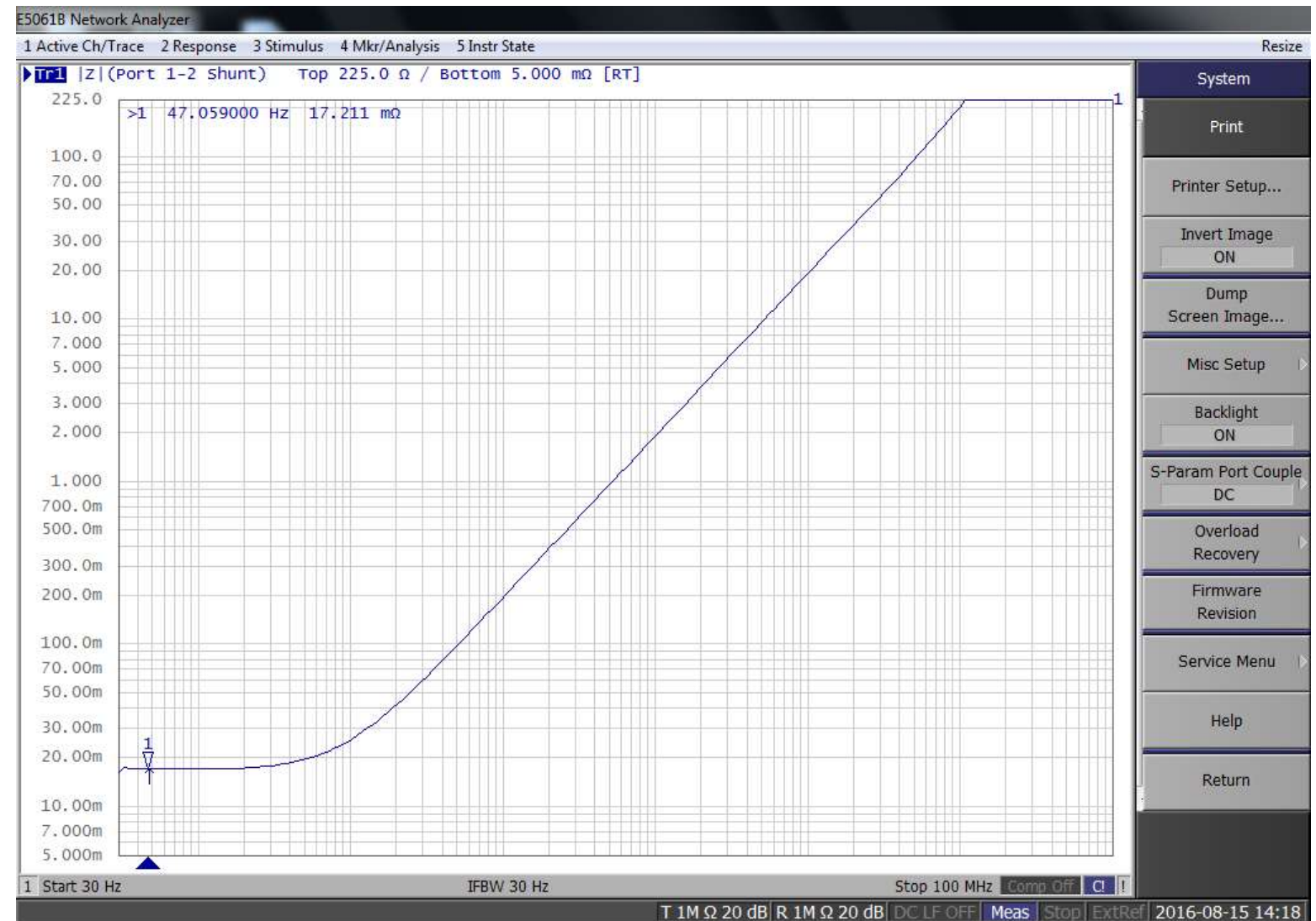
OPTIMIZER DETERMINED COMPONENT VALUES

C1_val	C2_val	C3_val	L1_val	L2_val	R1_val	R2_val	R3_val	R4_val
234.522	95.478	23.176	1.760	0.447	30.000	10.046	4.913	18.813





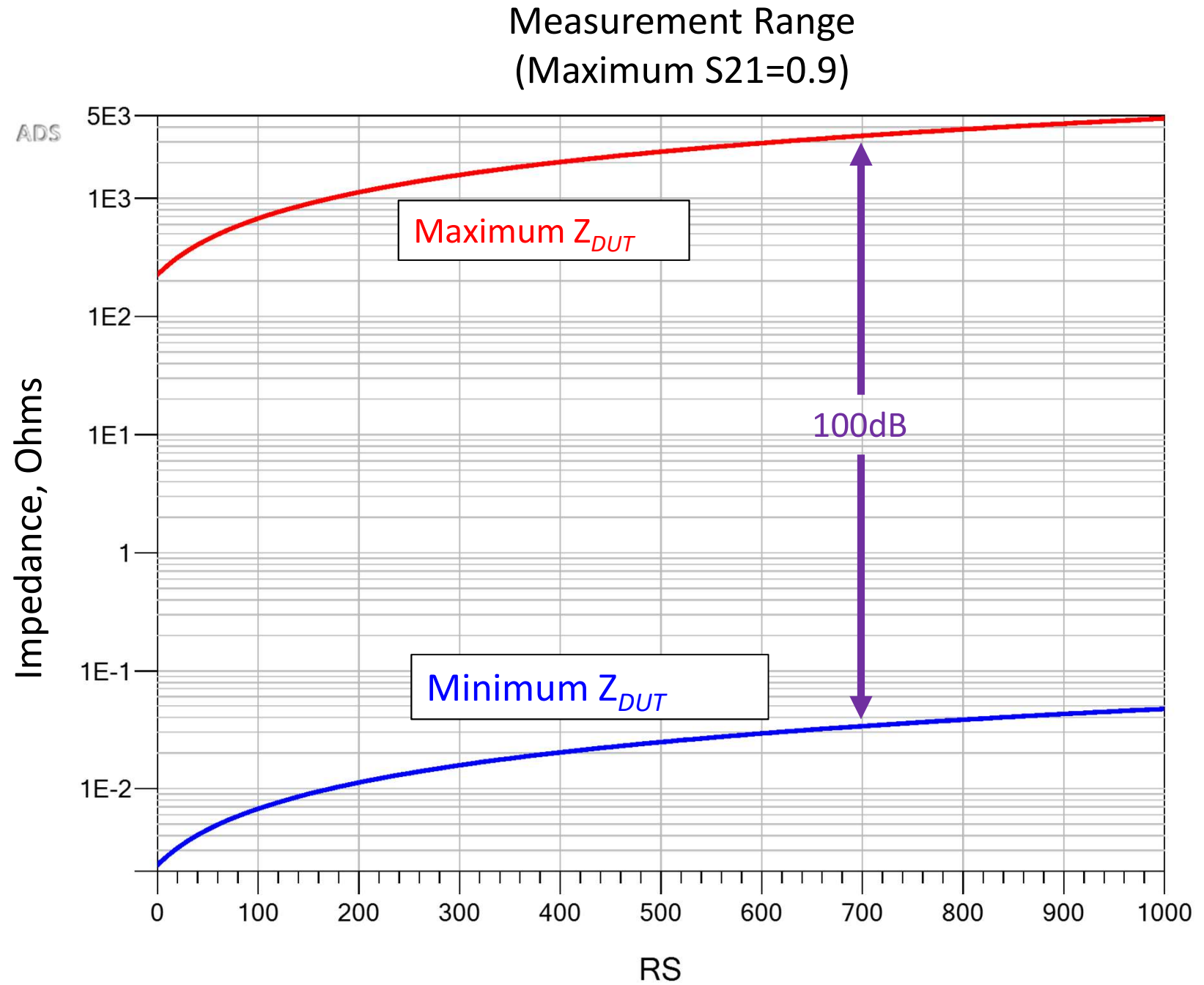
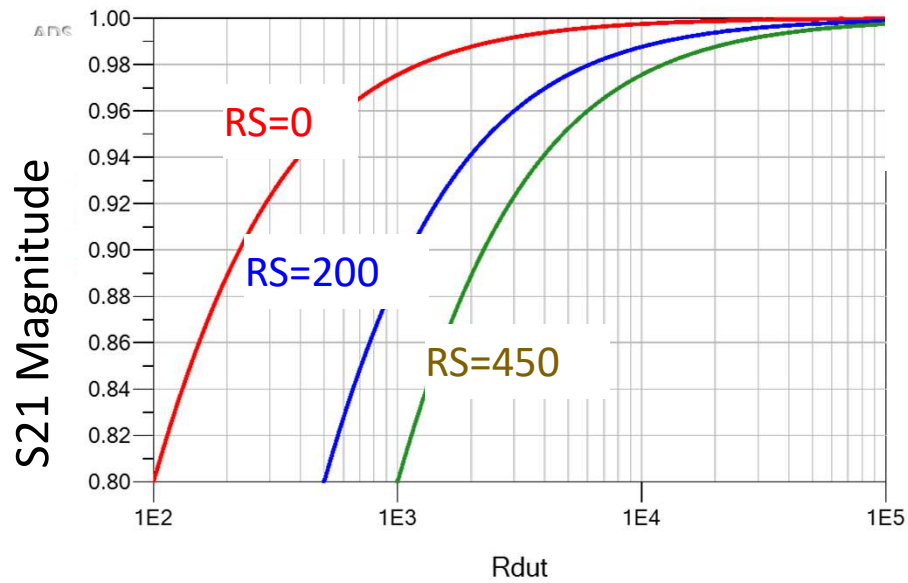
Inductors and Ferrite Beads

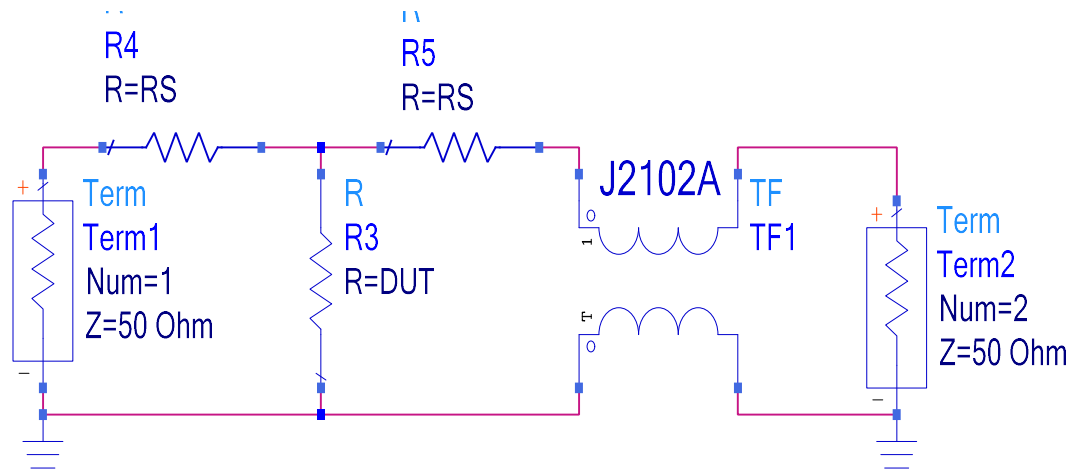


$$S_{21} = \frac{2 \cdot Z_{DUT}}{2 \cdot Z_{DUT} + Z_{ref} + R_S}$$

$$Z_{DUT} = \frac{Z_{ref} + R_S}{2} \frac{S_{21}}{1 - S_{21}}$$

Increasing R_S

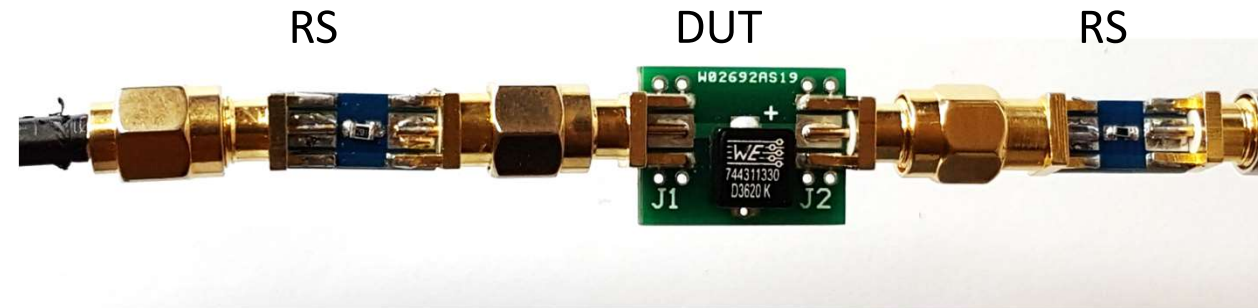




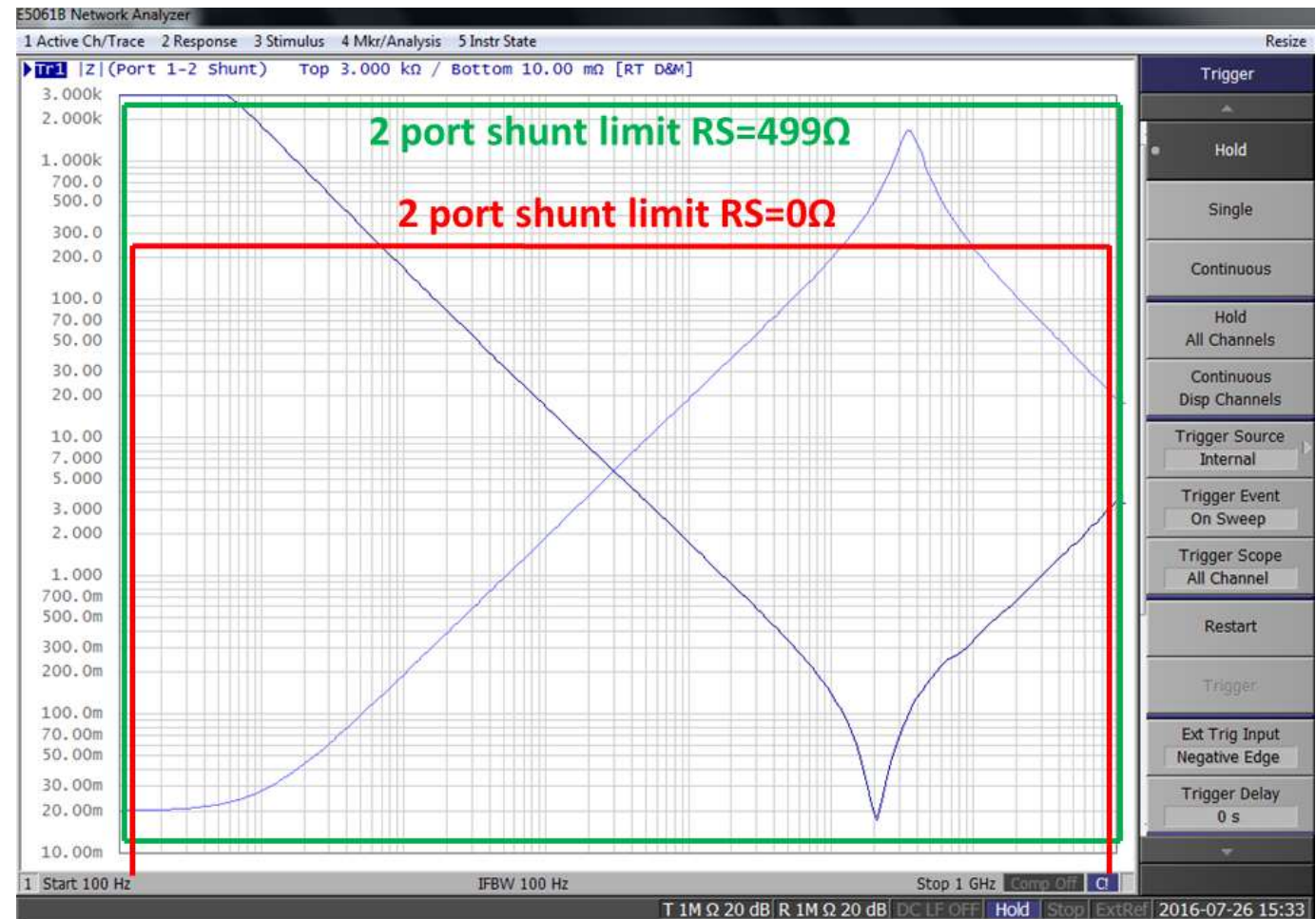
$$Z_{DUT} = \frac{Z_{ref} + R_s}{2} \frac{S_{21}}{1 - S_{21}}$$

$$S_{21} = \frac{2 \cdot Z_{DUT}}{2 \cdot Z_{DUT} + Z_{ref} + R_s}$$

Series Resistor	Min Z	Max Z
200Ω	5 mΩ	1.125kΩ
450Ω	10 mΩ	2.25kΩ
499Ω	11mΩ	2.48kΩ
950Ω	20 mΩ	4.5kΩ



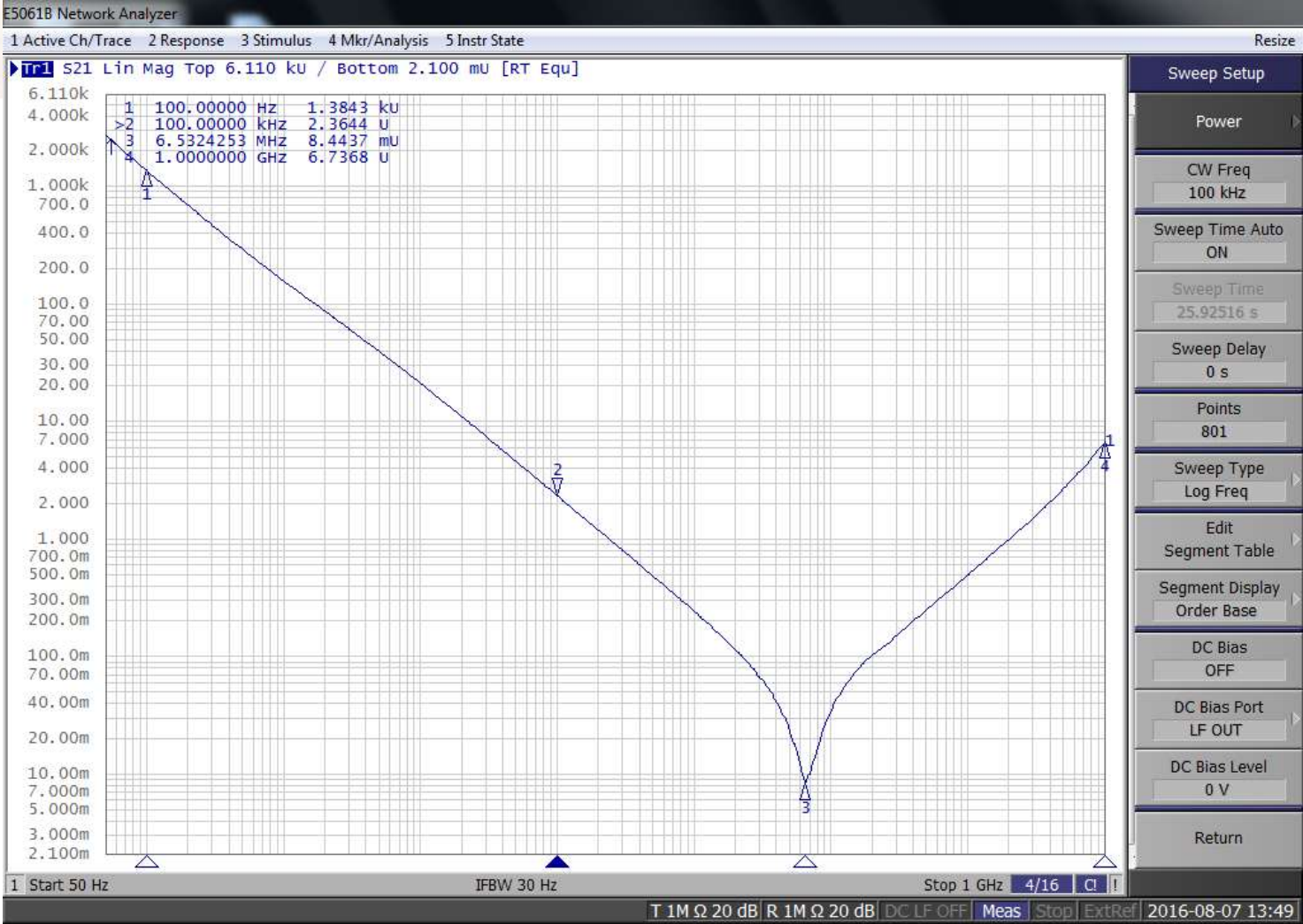
Measurement Range





0.1 uF Ceramic Capacitor

Measured Impedance, Ohms



Summary

- How to perform a modified 2-port shunt through measurement technique for high fidelity data
- Why different simulation models are needed for SPICE and EM simulators
- How an optimizer can help create the high fidelity models from the measurements

How to Video Workspace Demonstration

How to Design for Power Integrity:
Measuring, Modeling, Simulating
Capacitors and Inductors

Keysight EEsof EDA
"How to" Video

Steven Sandler
Founder
PICOTEST

Author of
Power Integrity
A McGraw-Hill
publication.

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Thank You!

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Questions?